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An Aeromagnetic Survey of Southwestern Illinois

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AN AEROMAGNETIC SURVEY OF SOUTHWESTERN ILLINOIS

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ABSTRACT

An aeromagnetic survey of southwestern Illinois was flown at an elevation of 3,000 feet above mean sea level, with traverses oriented north-south at 1-mile intervals.

The area covered by the survey is the structural transition zone between the Ozark Dome on the west and the deepest part of the Illinois Basin on the east. The southernmost part of the surveyed area includes the northern tip of the Mississippi Embayment.

Lateral susceptibility contrasts producing observed magnetic anomalies result from topography on the crystalline basement surface and from lithologic changes within the basement rocks above the Curie Point Geotherm. Theoretical analyses of some of the larger observed magnetic anomalies indicate that they were caused by basic intrusive bodies whose main masses are located beneath the basement surface.

Although there is reason to believe that the deepintrusive activity hypothesized for the study area may, in some cases, have occurred as long ago as Precambrian, much of the intrusive activity is thought to have taken place at several times in the Paleozoic and possibly as late as Cretaceous time.

INTRODUCTION

This report presents the results of an aeromagnetic survey of southwestern Illinois conducted for the Illinois State Geological Survey by Professor William J. Hinze and co-workers at the Department of Geology, Michigan State University, in 1971. The survey covered that part of Illinois south of 39° N. latitude and west of 89° W. longitude (fig. 1).

Total magnetic intensity observations were made with an Elsec type 592 J proton free-precession magnetometer trailed behind a Cessna 182 aircraft. Flight elevation was 3,000 feet above mean sea level, and traverses were oriented north-south at 1-mile intervals.

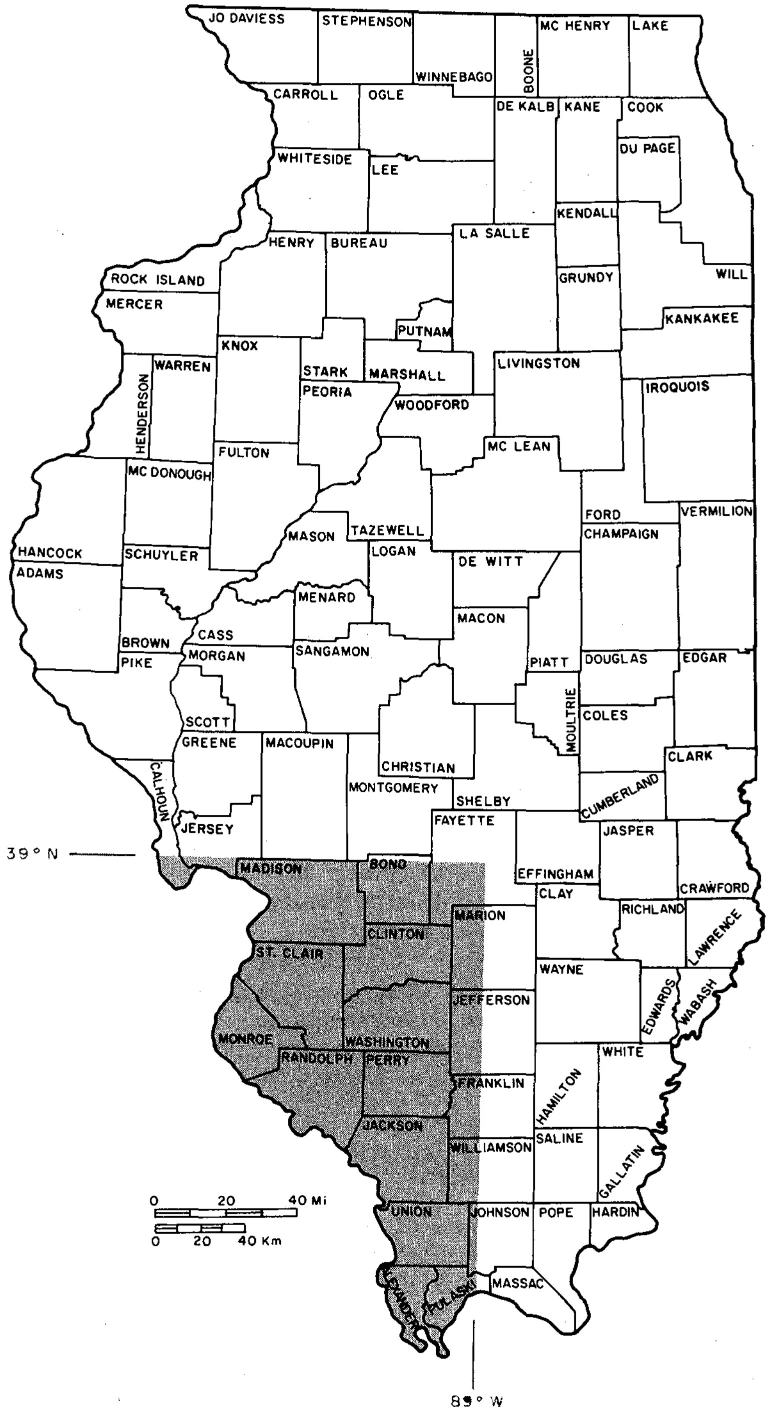


Fig. 1 - Map of Illinois showing area covered by aeromagnetic survey of southwestern Illinois.

This type of survey was performed to prospect for additional mineral resources in this area. Because the magnetic susceptibilities of igneous rocks normally are extremely great compared with those of sedimentary rocks, we thought that such a survey would yield information about the configuration and nature of the igneous rocks and the relation of these rocks to the structural history of the area. We hoped that the survey would reveal sedimentary structures that might contain oil; areas of igneous activity possibly associated with accumulations of fluorspar, lead, and zinc; and iron ore deposits similar to those found in southeastern Missouri.

Previously published magnetic maps that touch the area of investigation are restricted to a ground vertical magnetic intensity map based on one observation per county (McGinnis and Heigold, 1961) and an aeromagnetic map with four traverses crossing parts of the study area (Zietz and Kirby, 1968). Of particular relevance to this study is an aeromagnetic survey of southeastern Illinois (Patenaude, 1964) (fig. 7) flown at 3,000 feet above mean sea level, with north-south traverses at 6-mile intervals. The latter survey covers the area in Illinois south of 39° N. latitude and east of 89° W. longitude, and thus is the southeastern Illinois complement to our southwestern Illinois aeromagnetic survey.

The Illinois State Geological Survey has conducted a gravity survey of the entire state on approximately 1-mile grid spacing (McGinnis et al., 1976). A portion of the data from the gravity survey was used in an unpublished report by Schafersman (1973) to analyze some of the more sizable gravity anomalies in the study area.

In addition to the studies cited, there are several unpublished magnetic and gravity studies over parts of the area of investigation (McClure, 1931; Mateker, 1956; Chang, 1958; Douthit, 1959; Segar, 1965; Tikrity, Mateker, and Hinchley, 1967).

Acknowledgments

The author wishes to express his appreciation to Professor William J. Hinze of the Department of Geosciences, Purdue University, who was project manager of this survey while he was at Michigan State University and whose detailed description of the collection, compilation, and reduction of the aeromagnetic data is included almost verbatim in this report. Under Professor Hinze's direction, the survey crew consisted of Richard L. Kellogg, party chief-navigator; Wayne W. Wilson, instrument operator-technician; and Stuart D. Hanson, technician. Professor Lyle D. McGinnis of the Department of Geology at Northern Illinois University provided several useful suggestions in the interpretation phase of the study. Robert W. Ringler of the Survey staff helped prepare this manuscript.

The author is solely responsible for the analyses and interpretations.

AGE AND LITHOLOGY OF THE PRECAMBRIAN ROCKS IN AND NEAR THE STUDY AREA

Three deep borings within the study area and one deep boring just northeast of the area (table 1) have penetrated the Precambrian basement rocks. Granite was encountered in three of the borings, and rhyolite was encountered in the fourth (Bradbury and Atherton, 1965).

TABLE 1 - BASEMENT TESTS IN AREA COVERED BY AEROMAGNETIC SURVEY OF SOUTHWESTERN ILLINOIS (after Bradbury and Atherton, 1965)

1. Maryland Service No. S-1 Kircheis
   Madison County
   Sec. 27, T. 3 N., R. 6 W.
   Elevation - 504 ft
   Total depth - 5,018 ft
   Top of basement - 4,506 ft (datum mean sea level)
   Magnetic susceptibility - 288.45×10^{-6} cgs units
   Rock type: red granite

2. Mississippi River Fuel No. A-15 Theobold
   Monroe County
   Sec. 35, T. 1 S., R. 10 W.
   Elevation - 666 ft
   Total depth - 2,768 ft
   Top of basement - -2,093 ft (datum mean sea level)
   Magnetic susceptibility - 76.39×10^{-6} cgs units
   Rock type: red granite

3. Texaco No. 1 R. A. Johnson
   Marion County
   Sec. 6, T. 1 N., R. 2 E.
   Elevation - 541 ft
   Total depth - 9,210 ft
   Top of basement - 8,629 ft (datum mean sea level)
   Magnetic susceptibility - 240.61×10^{-6} cgs units
   Rock type: granite

4. Humble No. 1 Weaber-Horn*
   Fayette County
   Sec. 28, T. 8 N., R. 3 E.
   Elevation - 536 ft
   Total depth - 8,616 ft
   Top of basement - 7,676 ft (datum mean sea level)
   Magnetic susceptibility - 119.23×10^{-6} cgs units
   Rock type: rhyolite, upper part altered

*Well is not located in area covered by aeromagnetic survey (south of 39° N. lat. and west of 89° W. long.). It is just off northeast corner of surveyed area.

According to Lidiak et al. (1966), these rocks are some 1.2 billion to 1.5 billion years old. Bass (1960) reports that Precambrian igneous rocks from wells to basement in Indiana and Illinois are similar to those cropping out in the St. Francois Mountains of Iron, Madison, and St. Francois Counties, Missouri.

Andesites and basaltic rocks are exposed in Missouri as intrusives into the granites and rhyolites (Hayes, 1961a). Similar rocks have been encountered in borings in Indiana, where they have been interpreted as flows younger than the granite and possibly related to the Keweenawan lavas of upper Michigan (Greenberg and Vitaliano, 1962). Also, rocks identified as metasediments have been found in drill samples from basement rocks in Missouri (Hayes, 1961b) and Indiana (Kottlowski and Patton, 1953); however, Bass (1960) thought that the Indiana samples may be aphanitic volcanics and tuffs rather than metasediments. No Precambrian mafic igneous rocks have been encountered in Illinois.

DEPTH AND CONFIGURATION OF THE PRECAMBRIAN SURFACE

A contour map of the top of the Precambrian in Illinois prepared by Atherton and others in Bond et al. (1971) shows considerable relief on the basement surface in the study area (fig. 2). In Calhoun and Jersey Counties on the northwest and in Monroe and St. Clair Counties on the west, the Precambrian surface is less than 3,000 feet below mean sea level, whereas, in Williamson and Johnson Counties on the southeast, it is more than 12,000 feet below mean sea level. Because of the paucity of data (only 21 holes have penetrated basement in Illinois) and the fact that many of the deep borings that penetrate the basement were drilled on structural highs, the Precambrian surface probably is shown shallower and smoother than it is.

The Precambrian surface probably was considerably eroded before Cambrian sedimentation, but the several hundred feet of local relief may be confined to monadnocklike areas. Two wells spaced less than 8 miles apart in Pike County show a relief of approximately 800 feet in the Precambrian surface (Workman and Bell, 1948).

A map of the Precambrian surface of Missouri showing the major structural lineaments has been prepared by Kisvarsanyi (1975). This map is more detailed than its Illinois counterpart because many more holes have been drilled to the Precambrian surface, which is generally shallower than in Illinois, and because the Precambrian surface actually crops out extensively in the St. Francois Mountains of southeastern Missouri.

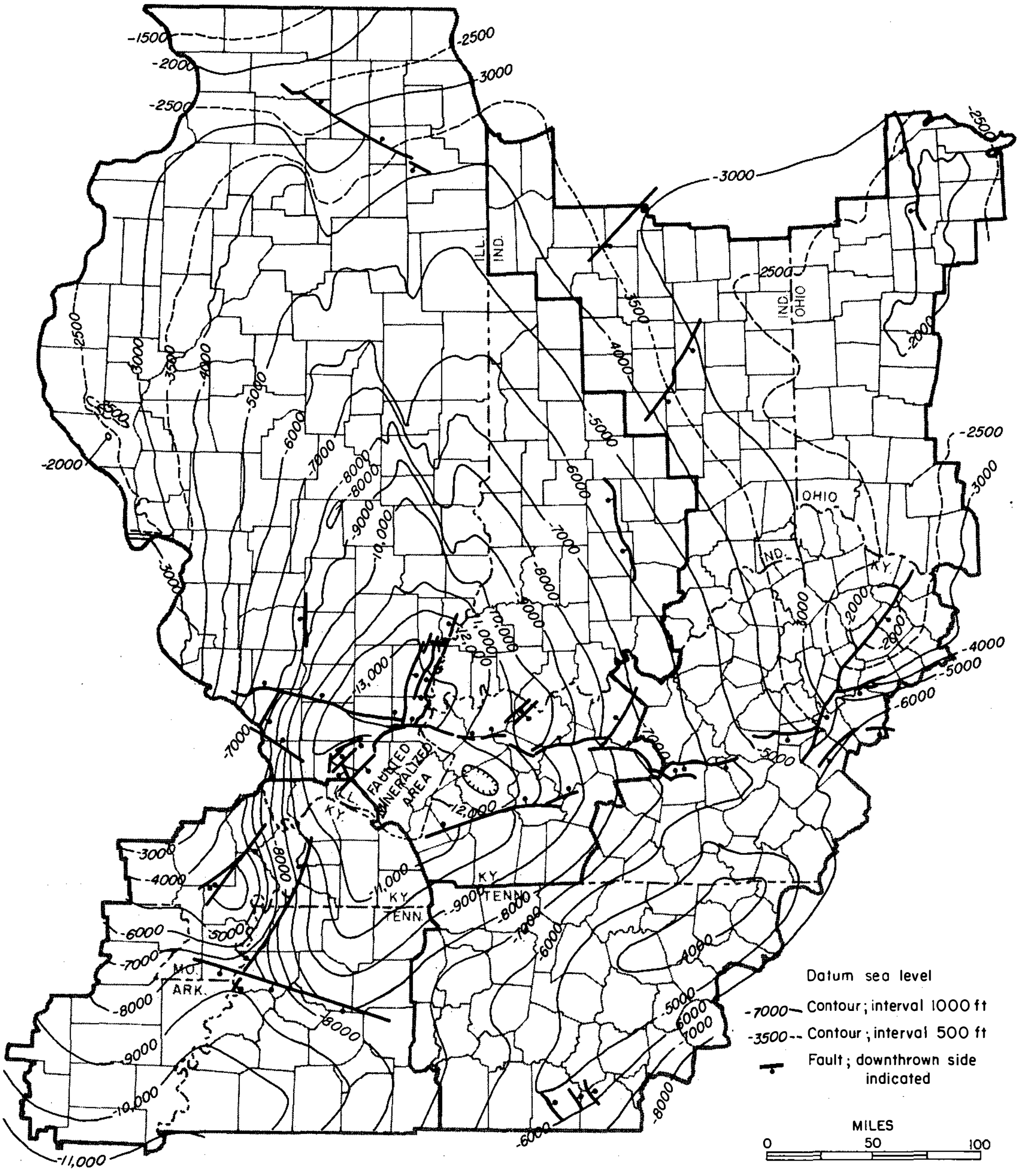


Fig. 2 - Structure of top of Precambrian basement. Adapted from an illustration prepared by Elwood Atherton in cooperation with H. M. Bristol, T. C. Buschbach, L. E. Becker, T. A. Dawson, Howard Schwalb, E. N. Wilson, A. T. Statter, and J. H. Buehner for publication in AAPG Memoir 15 (Bond et al., 1971); used with permission of the American Association of Petroleum Geologists.

IGNEOUS INTRUSIVE ACTIVITY AROUND THE STUDY AREA

There is no known post-Precambrian igneous intrusive activity in the study area, although there is evidence of such activity to the east and to the west. Most of the known post-Precambrian igneous intrusions in Illinois are located in the Fluorspar District of Hardin and Pope Counties, and in Gallatin, Saline, and Williamson Counties (fig. 3). The Illinois-Kentucky Fluorspar District is an area described as a large oval dome that collapsed to form a mosaic of fault blocks and wedges. The doming may have been caused either by crustal forces that uplifted the strata and permitted magma to enter near the surface or by the pressure of a large body of magma intruded at considerable depth (Currier and Wagner, 1944; Heyl et al., 1965; Grogan and Bradbury, 1968; Hook, 1974; Trace, 1974).

Relationship of intrusive activity along the eastern end of the Cottage Grove Fault System to that of the Fluorspar District in Illinois is indicated by the petrographic similarity of the rocks and the common strike of the intrusive bodies in the two areas. However, the parallel strike of the faults and dikes along the eastern end of the Cottage Grove Fault System is in sharp contrast to the relationship between faults and dikes in the Fluorspar District, where major faults trend northeastward at essentially right angles to the strike of the dikes; the latter relationship was found by Warren (1956) in his study of the peridotite dikes of the Western Kentucky Fluorspar District. Igneous rocks generally occur in fractures of little or no displacement (Clegg and Bradbury, 1956).

Dikes and sills of mica peridotite and lamprophyre are the most common of the known intrusives in southeastern Illinois. Plugs of explosion breccia also occur. Although most dikes are no more than a few feet wide, a dike known to be 300 feet wide has been encountered in a coal mine in Saline County (Clegg and Bradbury, 1956). It has been postulated that Omaha Dome in Gallatin County is the result of the intrusion of a small mica peridotite laccolith (English and Grogan, 1948).

Intrusion of strata as much as 40 feet above the Herrin (No. 6) Coal Member of the Carbondale Formation is known. Pleistocene drift of Illinoian age has been observed lying directly over truncated dikes in Williamson County (Clegg and Bradbury, 1956). As most erosional levels of southern Illinois, including those that obviously truncate fluorspar deposits, are capped by Mounds Gravel of Pliocene-Pleistocene age, the mineralization is also pre-Mounds (Willman and Frye, 1970). Assuming that all of these intrusions are contemporaneous, these observations allow igneous intrusive activity in this area to be dated as post-Carbondale and pre-Mounds.

Zartman et al. (1967) established a Permian age from radiometric dating of several dikes in the Illinois-Kentucky Fluorspar District. Heyl and Brock (1961) provided a single lead-alpha date of 90 million to 100 million years B.P. on monazite from an intrusive breccia from the Hicks Dome area (fig. 3). This date suggests that there may have been intrusive activity in this area as late as the middle of the Cretaceous. Kidwell (1951) mentioned that similar intrusive rocks of late Cretaceous age have been found in deep wells near the axis of the Mississippi Embayment from Memphis north to the New Madrid-Reelfoot Lake area.

Basic intrusive rocks of Precambrian age are abundant in southeast Missouri. Small diabase dikes are common throughout much of the area. A few large bodies up to several hundred feet in width and 2 to 3 miles in length crop out along an east-west zone in the Fredericktown-Ironton area. Several occurrences of diorite and gabbro are known from subsurface information. Some of these may represent large bosses or stocks thought to be associated with the Midcontinent Phase of Precambrian intrusive activity (Snyder and Wagner, 1961).

Kimberlite diatremes and peridotite intrusions into the sediments have been recognized in Ste. Genevieve and St. Francois Counties, Missouri (Zartman et al., 1967). These intrusions cut Cambrian strata. Devonian fossils in limestone xenoliths in the diatremes have dated these diatremes as Early Devonian and earliest Middle Devonian. Biotites from two peridotite-bearing diatremes were dated radiometrically at 390 million years, which suggests Early and Middle Devonian age. Lack of Mississippian rocks in diatremes here indicates pre-Mississippian age for emplacement. According to Heyl (1972), these intrusions are located at the northwest end of the fractured and brecciated Farmington Anticline near the Palmer, Big River, and Ste. Genevieve Fault Zones. Because the Ste. Genevieve Fault Zone began developing in Devonian time, deep-seated access channels for intrusions were likely provided at that time.

At the eastern end of the Kentucky River Fault Zone in Elliott County, Kentucky, there are peridotite and kimberlite diatremes and dikes intruded into the sediments. Inclusions of eclogite and granulite are especially abundant in the kimberlites. Radiometric dating yielded an early Permian age of 269 million years B.P. (Zartman et al., 1967).

Along what Heyl (1972) refers to as the 38th parallel lineament (fig. 4), many of the known intrusions appear to occur in swarms. This observation and the wide range in age of the intrusions along this line suggest that the intrusions are associated with faults deep in the earth's crust, not necessarily continuous, along which movements took place in the Paleozoic and possibly into Mesozoic time.

STRUCTURAL FRAMEWORK OF SOUTHWESTERN ILLINOIS

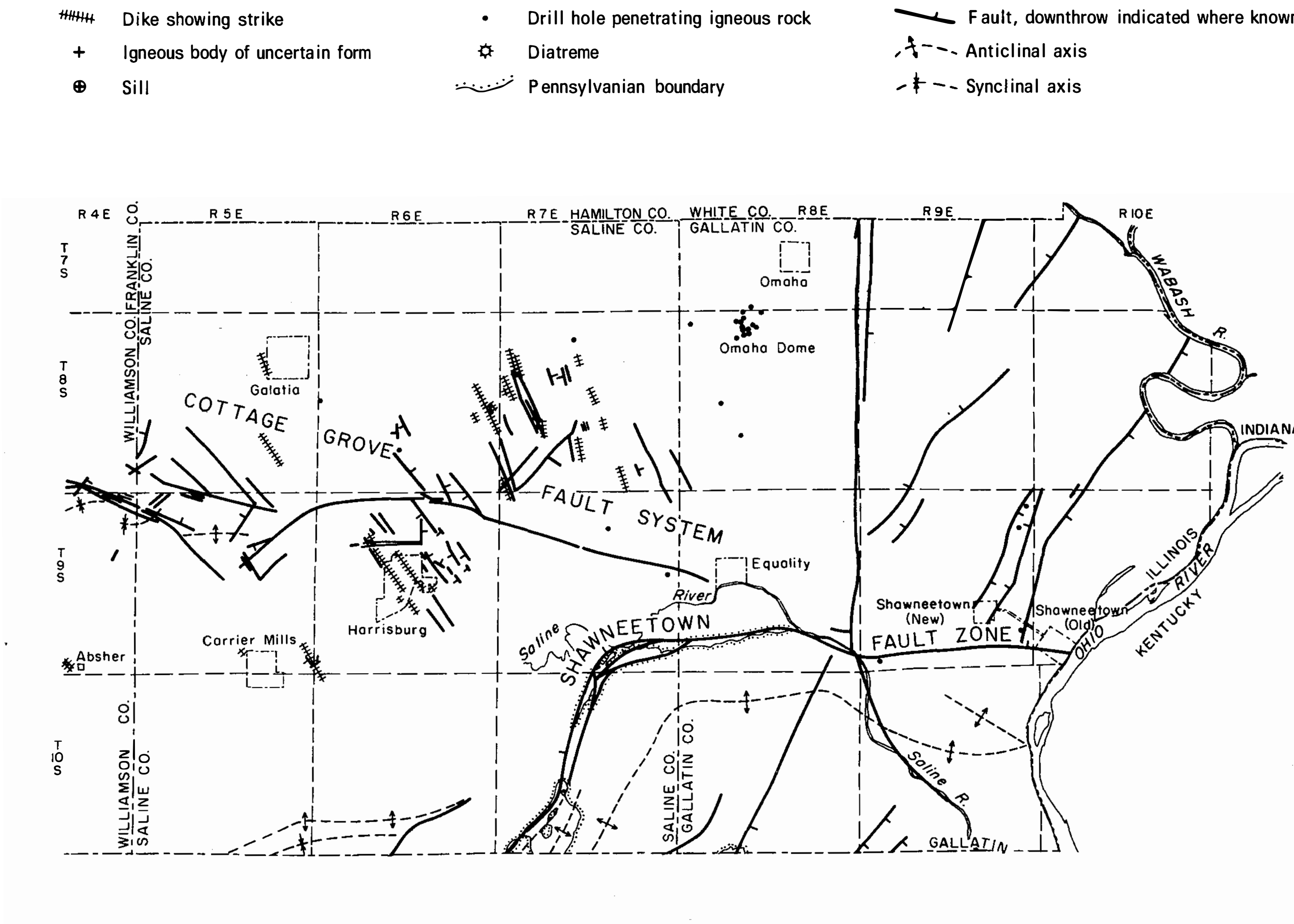
The southwestern Illinois survey area is located on the western flank of the Illinois Basin and the eastern slope of the Ozark Dome. The southernmost part of the surveyed area includes the northern tip of the Mississippi Embayment (fig. 5).

Sedimentary rocks in the study area range in thickness from about 3,000 feet on the west to more than 12,000 feet on the east. For the most part, these rocks are Paleozoic in age and are covered with a thin veneer of glacial drift. In the extreme southern part of the surveyed area, beyond the limits of the glacial deposits, Mesozoic (Cretaceous) and Cenozoic (Tertiary) rocks also crop out.

Within and around the study area, there are several major structures. These structures are well known from their expressions in the sedimentary rocks, and they extend into the basement rocks.

Most of the area of investigation corresponds to the southern part of the Western Shelf (fig. 5). The shelf is bounded on the east by the Du Quoin Monocline and on the west by the Ozark Dome.

The Illinois part of the Ste. Genevieve Fault Zone (fig. 5) extends from the extreme southwest corner of Jackson County, Illinois, southeastward into north-central Union County, Illinois. It is downthrown to the northeast, and relative displacements due to folding and faulting approach 2,000 feet (H. M. Bristol, personal communication, 1975). The cause of this folding and faulting is thought to have been compressional forces that affected the border of the Ozark region (Weller and Ekblaw, 1940). The faulting probably originated in post-Mississippian-pre-Pennsylvanian time and was subsequently accentuated during and after Pennsylvanian time (Ekblaw, 1925; Weller and Ekblaw, 1940; Desborough, 1959, 1961b).


Dike showing strike
Igneous body of uncertain form
Sill
Drill hole penetrating igneous rock
Diatreme
Pennsylvanian boundary
Fault, downthrow indicated where known
Anticlinal axis
Synclinal axis
R4E
R5E
R6E
R7E
R8E
R9E
R10E
T7S
T8S
T9S
T10S
HAMILTON CO.
SALINE CO.
WHITE CO.
GALLATIN CO.
FRANKLIN CO.
WILLIAMSON CO.
SALINE CO.
Omaha
Omaha Dome
Galatia
COTTAGE GROVE FAULT SYSTEM
Equality
Saline River
SHAWNEETOWN FAULT ZONE
Shawneetown (New)
Shawneetown (Old)
Harrisburg
Carrier Mills
Absher
WABASH R.
INDIANA
ILLINOIS
OHIO RIVER
KENTUCKY
Saline R.
GALLATIN

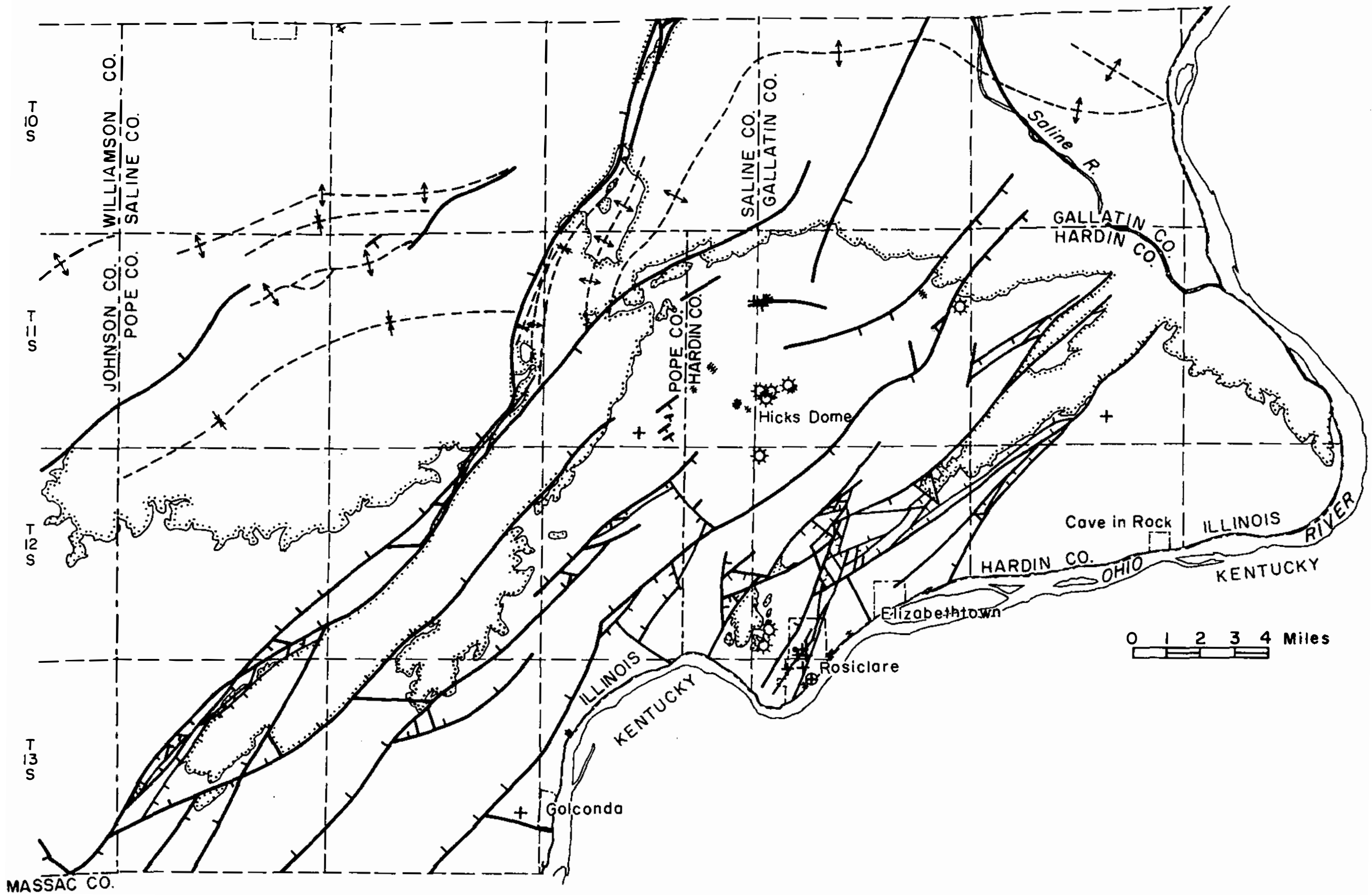


Fig. 3 - Distribution of igneous intrusive rocks in Illinois (modified from Clegg and Bradbury, 1956).

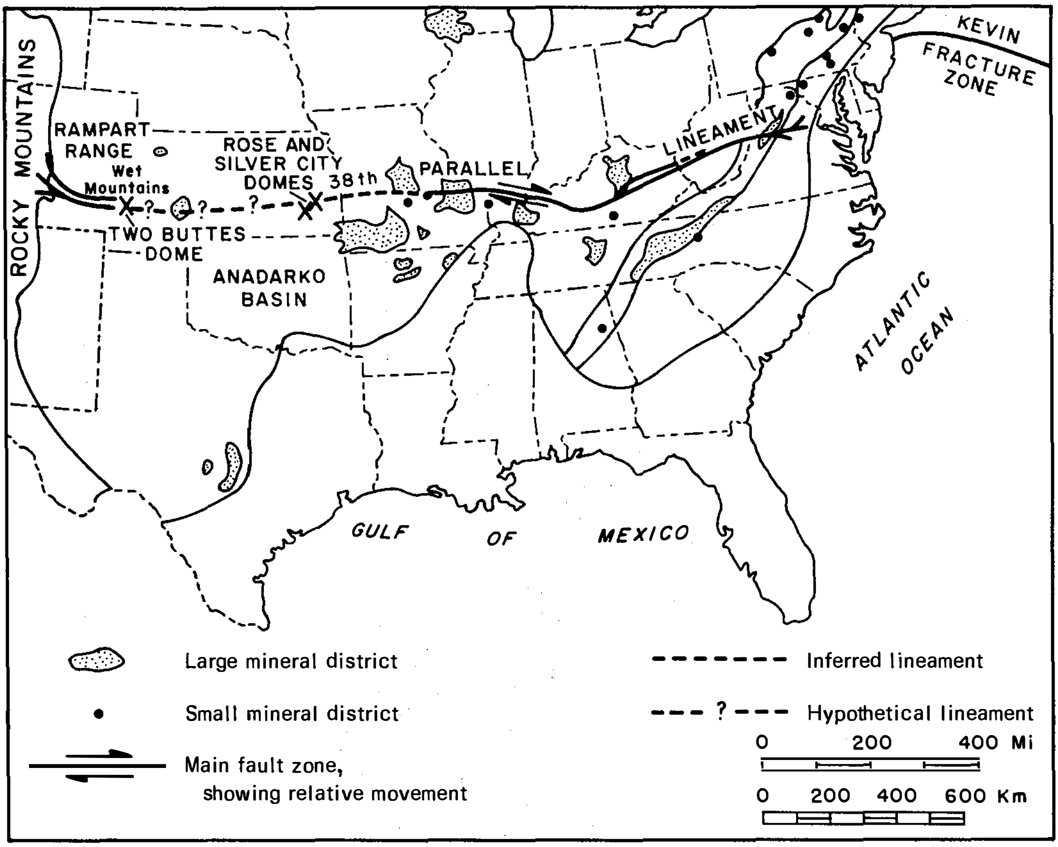


Fig. 4 - Location of the 38th parallel lineament (after Heyl, 1972). Used with permission of Economic Geology.

The Cap au Grès Faulted Flexure is a narrow zone of intense deformation extending continuously from western Pike County, Missouri, southeastward through Lincoln County, Missouri, then eastward into Illinois across southern Calhoun County, Illinois, and into southwestern Jersey County, Illinois, where it disappears beneath the Mississippi River alluvial plain. The average trend in Illinois is about N. 87° W. The total structural relief along the faulted flexure ranges from 750 to 1,200 feet, averaging about 1,000 feet, and the north side is upthrown. The principal movement along the Cap au Grès Faulted Flexure was post-St. Louis (Mississippian) and pre-Pennsylvanian. Movements also occurred during both earlier and later periods. Post-Pennsylvanian movement was particularly significant (Krey, 1924; Cole, 1961; Koenig, 1961; Rubey, 1952).

The Cottage Grove Fault System (fig. 5) extends across southern Illinois from a point just north of where the Shawneetown Fault Zone turns south near Equality in Gallatin County, Illinois, to southeastern Randolph County, Illinois, where it appears to die out. The alkaline peridotite dikes occurring in some of the northwest-trending tension fractures on the east end of this fault system are evidence that the fracture system extends deep into the lower crust. Stratigraphic relationships along the Cottage Grove Fault System indicate that this system of

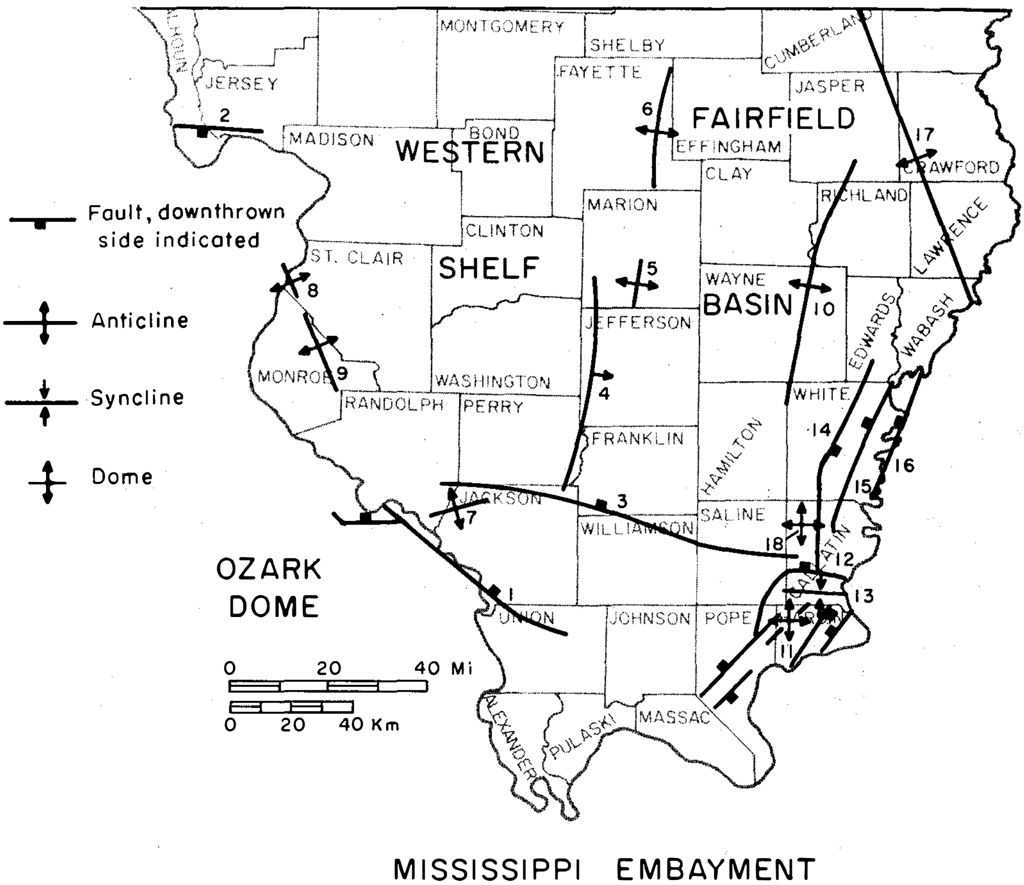


Fig. 5 - Structural features in and around the southwestern Illinois study area (modified from Clegg, 1970). 1 - Ste. Genevieve Fault Zone; 2 - Cap au Grès Faulted Flexure; 3 - Cottage Grove Fault System; 4 - Du Quoin Monocline; 5 - Salem Anticline; 6 - Louden Anticline; 7 - Ava-Campbell Hill Anticline; 8 - Dupo Anticline; 9 - Waterloo Anticline; 10 - Clay City Anticlinal Belt; 11 - Hicks Dome; 12 - Shawneetown Fault Zone; 13 - Eagle Valley Syncline; 14 - Ridgway Fault; 15 - Herald-Phillipstown Fault; 16 - Maunie Fault; 17 - La Salle Anticlinal Belt; 18 - Omaha Dome.

predominantly normal faults was active late in the Paleozoic, the largest amount of movement having taken place near the end of the Paleozoic. Displacements are less than 250 feet (H. M. Bristol, personal communication, 1976). According to Heyl (1972), the alkaline peridotite dikes were intruded during a period of structural tension and movement along the system in Pennsylvanian and Permian time.

The Du Quoin Monocline (fig. 5) is a belt of relatively steep, eastward-dipping strata extending from Elkville in northeastern Jackson County, Illinois, approximately N. 10° E. along the eastern side of Perry County to a point about 20 miles north of Centralia. By comparing the thicknesses of the Abbott Formation (lower part of Pennsylvanian) on both sides of the monocline, Desborough (1961a) determined that the development of the monocline began during the deposition of the Abbott.

The Salem and Louden Anticlines (fig. 5) are two of the major oil- and gas-producing structures on the west edge of the Fairfield Basin. The Louden Anticline is located in northeastern Fayette County, Illinois, and the Salem Anticline is in the southwestern part of Marion County, Illinois. The major axes of these structures trend northeasterly, and both structures possess more than 200 feet of closure on their producing formations (Cohee and Carter, 1940; Brownfield, 1954). Away from the crests of both anticlines, the steepest dips of the strata are to the west and northwest. According to DuBois (1951) and Brownfield (1954), the structural development on the Salem and Louden Anticlines originated in the early Pennsylvanian or possibly in the late Mississippian, continued throughout Pennsylvanian time, and terminated in late Pennsylvanian time or later.

In addition to these major structural features, there are some lesser structural features in the study area: the Ava-Campbell Hill, the Waterloo, and the Dupo Anticlines (fig. 5). The Ava-Campbell Hill Anticline in northern Jackson County is an elongate, irregular, asymmetrical structure trending about N. 55° E. from Sec. 30, T. 7 S., R. 4 W., to the western side of Sec. 6, T. 7 S., R. 3 W., where the trend changes to due east. The dips are steeper on the northwest, and the structure plunges to the northeast (Root, 1928; Bell, 1935, 1940). The Dupo Anticline is an elongate, asymmetrical structure near the town of Dupo in western St. Clair County. It trends about N. 10° W., with dips of about 2° to the east. The western flank is much steeper, with dips of 30° to 40° common. The Waterloo Anticline, to the south, in Monroe County, Illinois, is located between the towns of Columbia and Waterloo on what appears to be the same structural trend as the trend of the Dupo Anticline. This, too, is an elongate, asymmetrical structure, the west flank being the steeper side, with dips of about 10°.

COLLECTION, COMPILATION, AND REDUCTION OF AEROMAGNETIC DATA

Observations of the total intensity of the earth's magnetic field were made with an Elsec 592 J proton free-precession magnetometer manufactured by Littlemore Scientific Engineering Co., Oxford, England. The instrument is a reciprocal type (Hood and Ward, 1969), which has a sensitivity of approximately 3 gammas in this survey. The sensing unit is contained in an aerodynamically stabilized housing, which was trailed about 100 feet behind the Cessna 182 aircraft used in the flight operation.

The output of the instrument, which is inversely proportional to the earth's magnetic field, is displayed on an 8-inch chart recorder. Recording parameters and the aircraft's airspeed were established so that a horizontal distance of 1 inch on the chart represents a distance of approximately 1 mile on the ground. About eight observations per mile were obtained along the flight path. Variations in ground speed due to winds aloft caused the number of readings per mile to fluctuate, but never by more than two or three per mile.

Magnetic traverses were flown at a constant barometric altitude of 3,000 feet above mean sea level, or roughly 2,500 feet above the ground surface, along north-south section lines at 1-mile intervals. Navigation along these tracks was achieved by visual fixes on cultural and natural features. The geographic position of the magnetic observations was established by simultaneously keying fiducial marks on the magnetic charts and the navigation maps at the precise moment that the aircraft passed over a readily identifiable cultural or natural geographic feature.

These navigational fixes were made as frequently as possible along the tracks, usually at 1-mile intervals. Repeated observations along a test track indicate that the accuracy of locations along traverses is roughly equivalent to one cycling of the magnetometer, or approximately 600 feet.

To avoid high-amplitude and unpredictable time, or "diurnal," magnetic variations, surveying was not performed during periods for which magnetic storms had been predicted by the Space Disturbances Laboratory of the ESSA Research Center at Boulder, Colorado. Normal magnetic time variations were established, weather permitting, by repeated observations along a test traverse convenient to the base of operations at the beginning and termination of flight operations. Additional data for establishing these variations were obtained by making observations along a network of east-west control lines keyed into each north-south traverse line intersected by the control traverses. Twenty-one doubly-flown control traverses, that is, tracks observed by immediately repeating the traverse by a flight in the opposite direction, were flown east-west across the area at approximately 6-mile intervals. These control lines were in turn tied together by a doubly-flown north-south traverse.

Twenty days were spent in the field collecting data. During this period 112 hours of flight time were logged. Approximately 6,700 miles of north-south traverse data were recorded along with 2,100 miles of east-west control-line data.

The output of the magnetometer as observed on the chart recorder was converted into total magnetic intensity in gammas at each navigation point, at intermediate positions where the navigation points are separated by a distance greater than 1 mile, and at maximum and minimum points in the earth's magnetic field. These provide sufficient datum points for mapping the magnetic field because of the gentle gradients of the observed field.

The daily time variations in the magnetic field were established and were removed from the observed data by the following procedure. The time variations occurring during the observation of the east-west control lines were obtained from the repeated observations on these doubly-flown lines. These effects were then subtracted from the observed data and tied together with the master north-south traverse, which was corrected in the same manner. A control network having been established, the diurnal drift of the magnetic field of each point of intersection of the control network and the north-south traverses was determined by subtracting the control-network value from the observed value at the coincident point on the north-south traverses. The internal consistency of the calculated diurnal drift was checked by preparing daily graphs of the magnetic variations using times recorded at the intersecting points during the field operations. The test strip data recorded at the beginning and end of the flight operations provided additional data for the drift curves. The diurnal magnetic variations at the intersecting points established in this manner were applied as a linear function of distance to all datum points between the control values.

The normal spatial variations in the geomagnetic field were calculated by means of a computer program that uses 8 degrees of spherical harmonic expansion of the geomagnetic potential to define the field. The coefficients used in this program were determined by Cain et al. (1964). The total magnetic intensity for July 1970 was calculated over the survey area at an elevation of 3,000 feet above mean sea level. The results show that the total magnetic intensity increases by approximately 1,000 gammas from the southern to the northern boundary of the area. Magnetic values from a contour map of the normal geomagnetic field were subtracted from the observed magnetic intensities. The profile of the geomagnetic variations along each traverse was plotted on each magnetic chart.

The total magnetic intensity anomaly at each datum point was then calculated by subtracting the time and normal spatial variations of the geomagnetic field from the observed magnetic intensity. These values were plotted at the datum points that were previously located on a composite map prepared from an overlay of a mosaic of U.S. Geological Survey topographic maps (scale 1:62,500). The hand-contoured residual total magnetic intensity anomaly map prepared from these values is shown in plate 1.

CAUSES OF MAGNETIC ANOMALIES

Magnetic anomalies originate from horizontal variations in the magnetic polarization of the rocks from the surface to the Curie Point Geotherm of magnetite, the principal ferromagnetic mineral of rocks. In stable cratonic areas this geotherm, the surface below which magnetite loses its magnetic properties, is located in the lower crust or the upper mantle of the earth. Vacquier and Affleck (1941) have suggested that in such areas the bottom of the earth's magnetic crust is located from 11.4 to 15.7 miles below the earth's surface. This depth corresponds roughly to that interface in the lower crust separating the upper, granitic rocks from the lower, basic rocks. Seismologists refer to this contact as the Conrad Discontinuity. Magnetic polarization is caused by induction in the earth's magnetic field, a function of a rock's magnetic susceptibility, and by remanent magnetism. The latter factor generally is significant only as a source of magnetic anomalies from crystalline rocks, and particularly extrusive rocks.

Local concentrations of magnetite within the glacial drift may cause measurable anomalies at the surface. Moreover, facies changes and structural and erosional features within the sedimentary column may cause lateral lithologic contrasts that in theory may lead to lateral magnetic polarization variations. The remanent magnetization of sedimentary rocks is generally weak, and the magnetic susceptibility of these rocks is generally negligible (of the order of 10^{-6} cgs units) in comparison with that of igneous rocks. There are some notable exceptions. McGinnis and Heigold (1961) found a distinct magnetic low, measured at the surface, extending upstream from the mouth of the Illinois River, that was attributed to the absence of Pennsylvanian sediments, which here would have relatively high magnetic susceptibility. McEvilly (1957) has noted that several sedimentary formations in eastern Missouri have magnetic susceptibilities of about one-fourth of the normal value of granite. Ordinarily the effects of variations in the magnetic polarization of sediments are negligible at the flight elevations of aeromagnetic surveys.

Ultrabasic intrusives within the sedimentary rocks and similar to those intrusives found east and west of the study area along the 38th parallel lineament are possible sources of magnetic anomalies. Warren (1956), in a study of the dikes in the Western Kentucky Fluorspar District, has found that the remanent magnetic polarization associated with these ultrabasic intrusives is negligible in comparison to the induced magnetization. The magnetic susceptibility of these rocks commonly is moderately high (within the range of 10^{-3} to 10^{-2} cgs units), although nonmagnetic dikes do exist. In western Kentucky where the depth of overburden is less than 200 feet, most vertical magnetic intensity anomalies due to these dikes have a maximum amplitude of a few hundred gammas measured at the ground level, although an amplitude of 1,400 gammas has been observed over one dike. The amplitude of these anomalies would decrease rapidly with increasing vertical distance from the dike. At the flight elevation of this survey, these anomalies would have an amplitude of a few tens of gammas at most and widths of the anomalies at half the amplitude would be of the order of 1 mile. Thus, anomalies from similar dikes occurring in the study area would be difficult to discern.

Allingham (1964) reports that the granite rocks of the St. Francois Mountains in Missouri have negligible remanent magnetism and that the directions of the remanent vectors have a random distribution. He reports similar findings for the remanent magnetism of the rhyolites exposed in Stouts Creek within the St. Francois Mountains. However, Park (1968) reports that the black rhyolite of Cottoner Mountain in the St. Francois Mountains has an intensity of remanent magnetism of approximately 10^{-1} cgs units, which is about 40 times greater than the induced magnetism. The direction of the remanent magnetism vector of the black rhyolite is S. 30° W. and is inclined 35°. This direction compares favorably with the average direction of the remanent magnetism vector that he reports for the rocks in the St. Francois Mountains, S. 50° W., inclined 45°.

The magnetic susceptibilities of the granite and rhyolite samples obtained from the drill holes penetrating the basement in the study area range from 0.76×10^{-4} to 2.88×10^{-4} cgs units. Rudman and Blakely (1965) have found that the mean susceptibility of granite and rhyolite samples obtained from basement holes in Indiana, Illinois, and Ohio is generally less than 5.0×10^{-4} cgs units. McGinnis and Bradbury (1964) in an aeromagnetic study of the Hardin County, Illinois, area used a mean magnetic susceptibility value of 1.4×10^{-4} cgs units for the granite basement rocks in that area. Immediately to the west of the survey area in the St. Francois Mountains, the magnetic susceptibility of outcrop samples of granitic rocks is as high as 4.0×10^{-3} cgs units (Allingham, 1964). However, samples from scattered localities within the main part of the exposed granite batholith have susceptibilities between 0.5×10^{-3} and 1.0×10^{-3} cgs units. Higher magnetic susceptibilities are associated with granophyric rocks. Rhyolites exposed in the St. Francois Mountains have magnetic susceptibilities ranging from 2.0×10^{-3} to 4.5×10^{-3} cgs units (Allingham, 1964; Park, 1968). Schnepfe (1962) has reported susceptibility values from several hundred measurements on both exposed and subsurface Precambrian rocks in the St. Francois Mountain area. Mean susceptibility values for granitic and rhyolitic rocks are 7.15×10^{-4} and 6.76×10^{-4} cgs units, respectively.

Magnetic susceptibility data for basic igneous rocks are not as plentiful as those for granitic rocks. Warren (1956) has published susceptibilities of western Kentucky dike rocks determined from direct measurements. The values range from 0.045×10^{-3} to 9.0×10^{-3} cgs units, and the average susceptibility, estimated from six field traverses, is 3.80×10^{-3} cgs units. McGinnis and Bradbury (1964), applying a theoretical method outlined by Vacquier et al. (1951) to total magnetic intensity anomalies, obtained a value of 3.83×10^{-3} cgs units for a stock in the Hardin County area that was thought to be of the same composition as the peridotite dikes and sills encountered in that area. Schnepfe (1962) has collected susceptibility data on hundreds of samples of basic igneous rocks in the St. Francois Mountains area. The mean magnetic susceptibility for those samples is 4.73×10^{-3} cgs units.

If the Precambrian igneous rocks such as those exposed in the St. Francois Mountains extend into the study area, major magnetic anomalies can be expected. These may be related to topographic relief on a predominantly acidic basement surface and to variations within the susceptibilities of the granitic rocks and within the susceptibility and the remanent magnetism of the rhyolite. Also, trachyte, andesite, and diabase outcropping in the St. Francois Mountains have magnetic susceptibilities exceeding the values observed for the granophyre (Allingham, 1964).

An additional source of major magnetic anomalies in the study area might be iron ore bodies, which, like those that occur in the St. Francois Mountains, could occur as hydrothermal fracture fillings and as replacements in the Precambrian volcanics and pyroclastics. Several iron ore bodies in the sedimentary cover adjacent to the Precambrian outcrop area in Missouri have been located by the magnetic method (Snyder and Wagner, 1961).

INTERPRETATION OF AEROMAGNETIC DATA

The aeromagnetic map of southwestern Illinois (pl. 1) shows a range of values and a variation of patterns that suggest the presence of a crystalline basement of heterogeneous lithology. Under the assumptions that the sedimentary column has negligible magnetic susceptibility and that the igneous rocks of the study area have negligible remanent magnetism, the main task in the interpretation of the magnetic data is reduced to answering the question of whether the lateral susceptibility contrasts producing the observed anomalies are associated with topography on the crystalline basement surface or with lithologic changes within the basement rocks above the Curie Point Geotherm. In the following discussions we analyze specific anomalies and their causes. Where possible, we have related these anomalies to observed geologic structures; and wherever possible, we have used other geophysical data to aid in the interpretation.

In order to isolate the more prominent anomalies that may be obscured by mutual interference on the residual total magnetic intensity map, we systematically calculated curvature values over the study area by means of a finite difference technique outlined by Vacquier et al. (1951). Curvature data were also used to discern the fabric, or trends, in the magnetic field. Figure 6 shows the areas of positive and negative curvature over the study area. The general fabric of the magnetic field is aligned northeast-southwest except for a rather narrow band along the 38th parallel. This finding was not unexpected since the structural grain of the study area has a similar alignment. Finally, the curvature data were employed to calculate theoretical depths to anomaly-causing bodies and to corroborate depths obtained theoretically from the residual total magnetic intensity map (pl. 1).

Perhaps the most prominent anomalous feature on the residual total magnetic intensity map of the study area (pl. 1) is the high-gradient band (about 125 gammas per mile in central Jackson County) extending from a point in southern Randolph County where the 38th parallel intersects the Mississippi River to a point in western Williamson County near the southern edge of T. 9 S., R. 2 E. A previous aeromagnetic study of southeastern Illinois (fig. 7) by Patenaude (1964) shows that this high-gradient band actually extends entirely across southern Illinois to an area in southern Hardin County. This band is characterized by an increase in the residual total magnetic intensity values toward the north and a series of closed highs on the north side that are elongate in the east-west direction.

Across Illinois this band more or less follows the 38th parallel lineament (fig. 4) discussed by Heyl (1972). The 38th parallel lineament extends from northeastern Virginia to south-central Missouri, a distance of more than 800 miles, and may possibly extend farther both east and west. In Illinois this lineament is composed of the east-west part of the Shawneetown Fault on the east and the Cottage Grove Fault System on the west.

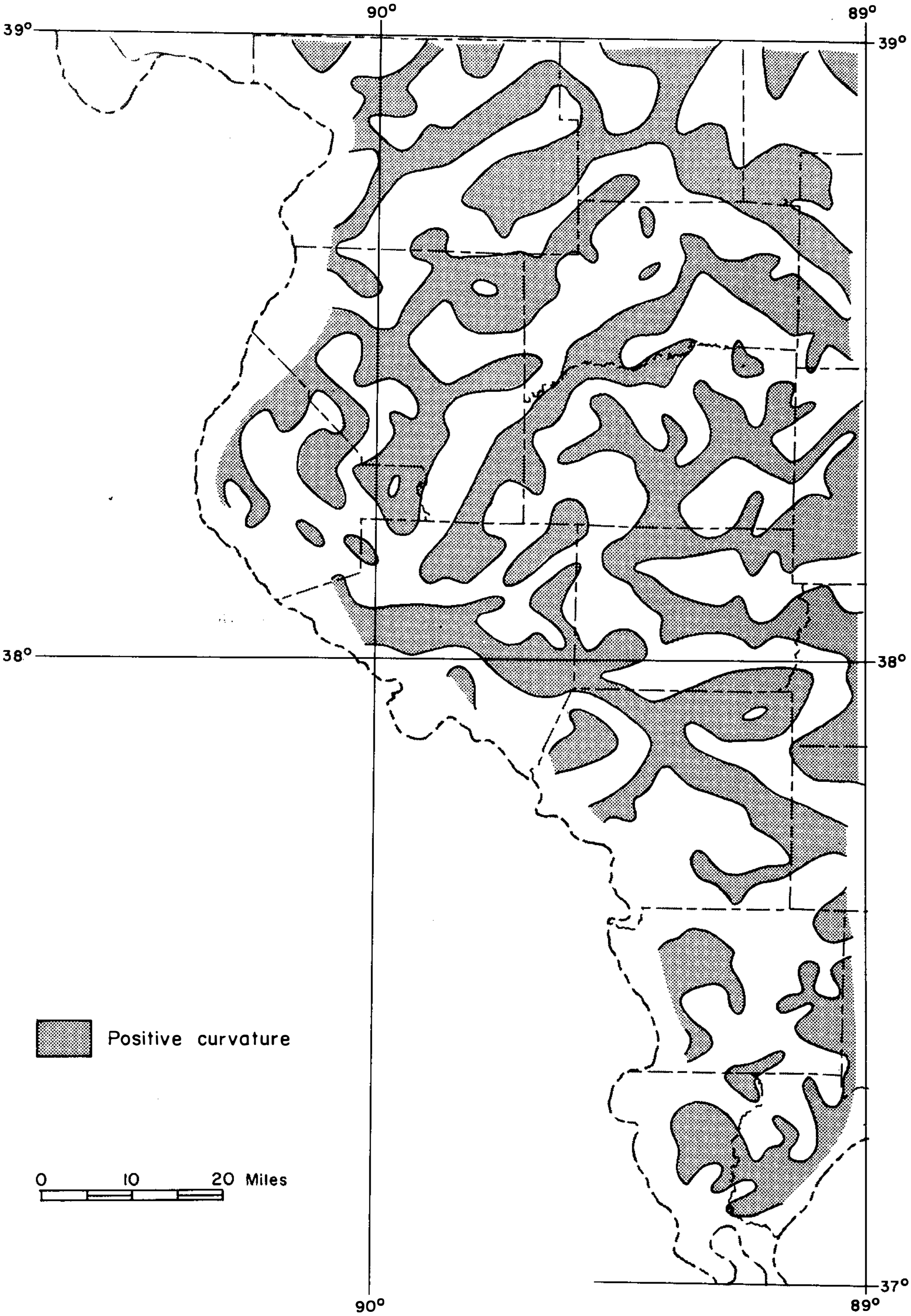


Fig. 6 - Residual total magnetic intensity curvature map of southwestern Illinois. Curvature values calculated by a technique outlined by Vacquier et al. (1951).

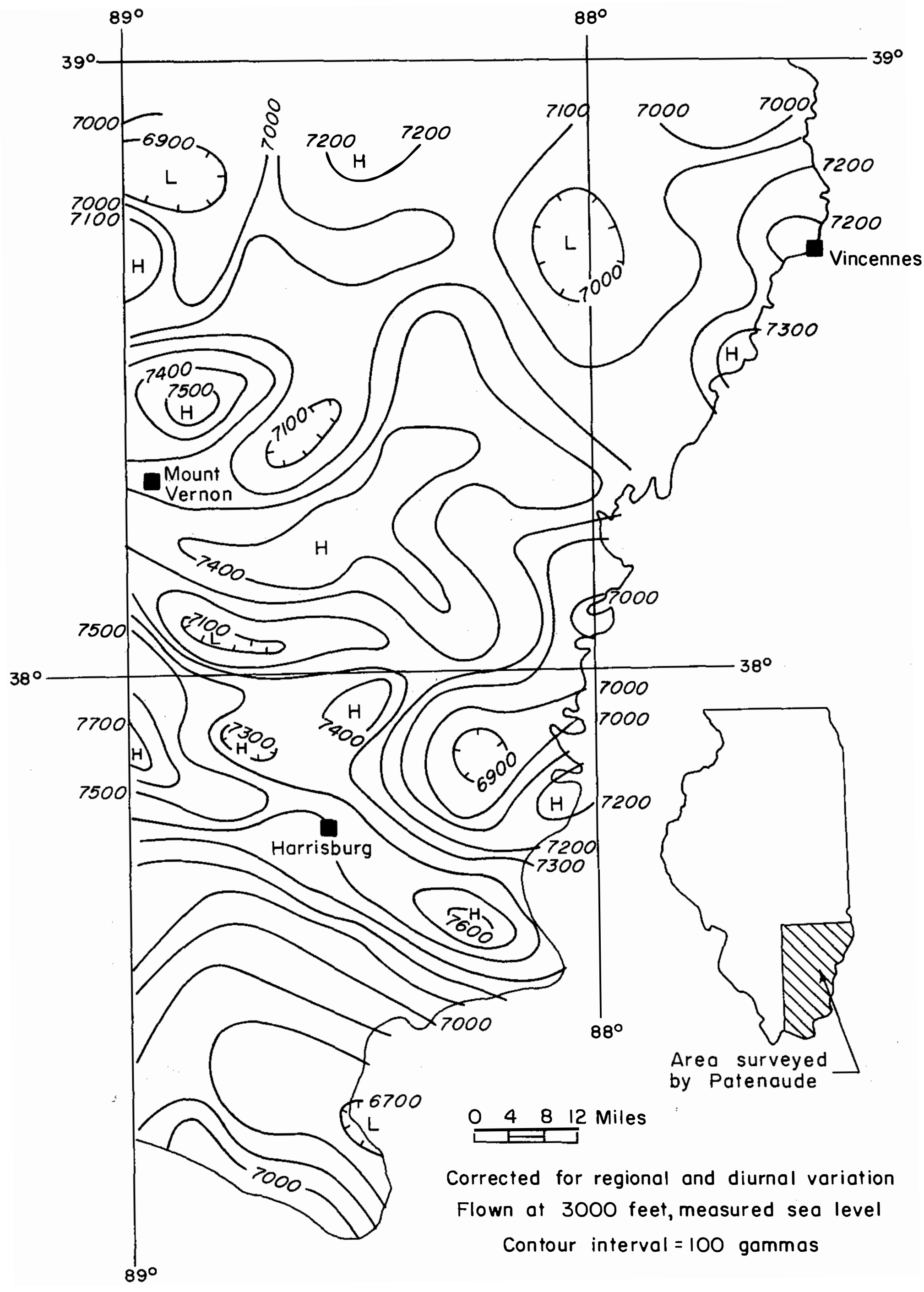


Fig. 7 - Total field aeromagnetic map of southeastern Illinois (after Patenaude, 1964).

McGinnis and Bradbury (1964) used aeromagnetic data from a survey flown at 1-mile flight-line spacing at an elevation of 2,000 feet above mean sea level to analyze a large, closed, positive anomaly centered in northern Hardin County, Illinois. This anomaly, which occurs on the northern side of the statewide band of high magnetic gradient, is confined to the upthrown side of the Shawneetown Fault. The long axis of this anomaly trends approximately N. 65° W. McGinnis and Bradbury have interpreted this anomaly to be the result of a stock of basic intrusive rocks at a depth of 11,000 feet or more with a magnetic susceptibility of 3.83×10^{-3} cgs units. The body causing this anomaly is likely mineralogically similar to shallower intrusives encountered in the area.

In the study area there are two prominent, closed, positive anomalies immediately to the north of the high-gradient band (pl. 1). One, labeled A, is located on the eastern end of the line separating Perry and Jackson Counties. The other, labeled B, is located in western Randolph County. Both anomalies were analyzed using techniques outlined by Vacquier et al. (1951). These techniques assume that the bodies producing the anomalies are infinitely long, vertically oriented, prismatically shaped bodies whose tops are located above the Curie Point Geotherm. The depth to the top of the body producing anomaly A was calculated to be about 11,730 feet (11,300 feet below mean sea level), and the susceptibility contrast to be 2.06×10^{-3} cgs units. The depth to the top of anomaly B was calculated by this method to be about 4,900 feet (4,400 feet below mean sea level), and the susceptibility contrast to be 4.02×10^{-3} cgs units.

Segar (1965), using vertical magnetic intensity data from a ground survey, has applied the half-slope method of Peters (1949) to a north-south profile across anomaly B in order to obtain a depth to the susceptibility contrast causing this anomaly. His results indicate a depth of approximately 5,100 feet below the surface. Segar further assumed that the body causing the anomaly was in the shape of a dike and applied the superposition method of standard curves developed by Gay (1963). This method yielded a depth of approximately 4,400 feet below the surface and a magnetic susceptibility contrast of 2.19×10^{-3} cgs units. This susceptibility indicates that the proposed body has a chemical composition similar to that of basalt.

From the analyses of the anomalies on the north side of the high-gradient band, it appears that a series of basic dikelike intrusions has taken place along Heyl's 38th parallel lineament across southern Illinois. The main masses of these intrusions appear to be at depths just below the basement surface. Dates obtained from igneous intrusive rocks in the sediments in southeastern Illinois and southeastern Missouri, to the east and west of the study area, respectively, are indicative of two or more distinct periods of intrusive activity along this structural lineament.

The high-gradient band which is so apparent on the residual total magnetic intensity map of the study area also dominates the vertical magnetic intensity map of a portion of this study area constructed by Segar (1965). The half-slope method of Peters (1949) was applied to a vertical magnetic intensity profile constructed in the direction of the steepest gradient in Tps. 6 and 7 S., R. 5 W., in Randolph County to determine the depth to the top of the lateral susceptibility contrast there (fig. 8). This method yielded a depth of 13,200 feet below the earth's surface to the top of the anomalous body.

The high-gradient band is the sort of anomaly that one might expect from a sharp lateral susceptibility contrast such as that resulting from a vertical fault. Nuttli (1955) has derived formulae for determining depth of faulting from magnetic

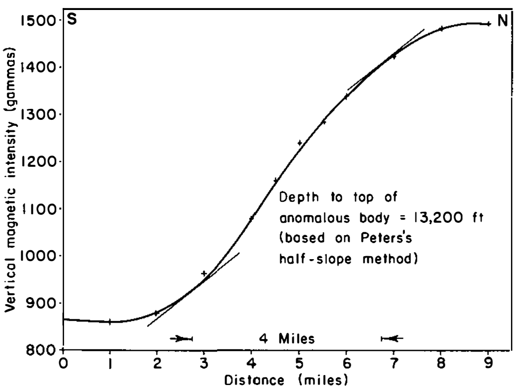


Fig. 8 - Vertical magnetic intensity profile perpendicular to high gradient band, Tps. 6 and 7 S., R. 5 W., Randolph County, Illinois. (Data from ground vertical magnetic survey by Segar, 1965.)

intensity measurements. Briefly, these formulae relate the mean depth of the anomalous slab to the horizontal distance between maximal and minimal values of vertical magnetic intensity along a profile perpendicular to the strike of the fault. From the vertical magnetic intensity profile in figure 8, a depth to the center of the theoretical anomalous slab of 19,700 feet below the surface was determined. This depth is consistent with the previous calculations made concerning this anomalous band. From the above analyses it is reasonable to infer a sharp lateral contrast in lithology somewhere below the basement surface and above the Curie Point Geotherm, with the more iron-rich, or basic, rocks on the north.

In addition to the previously discussed anomalies A and B, there are other sizable positive anomalies, C through L, on the residual total magnetic intensity map of southwestern Illinois (pl. 1). To each of these anomalies the method of Vacquier et al. (1951) was applied to determine the depth to the top of each anomaly-causing mass and the corresponding susceptibility contrast between this mass and the surrounding material. The results of these analyses are summarized in table 2.

In every case the depth to the top of the anomaly-causing body is at least as great as that of the basement surface at that point. In general, it appears that the anomalous bodies, like the basement surface, are shallower in the northern part of the study area. The susceptibility contrasts determined for these prominent anomalies are in all cases indicative of a lateral lithologic contrast such as that which would be produced by basic rocks in the upper crust.

Like the series of positive total magnetic intensity anomalies on the

TABLE 2 - THEORETICAL DEPTHS AND SUSCEPTIBILITY CONTRASTS OF ANOMALOUS MASSES ASSOCIATED WITH POSITIVE TOTAL MAGNETIC INTENSITY ANOMALIES IN SOUTHWESTERN ILLINOIS*

Anomaly (see plate 1)	Depth (ft below m.s.l.)	Susceptibility contrast ($\times 10^{-3}$ cgs units)
A	11,300	2.06
B	4,400	4.02
C	9,500	1.40
D	9,200	4.09
E	10,000	3.13
F	7,800	3.09
G	7,400	4.58
H	7,300	1.97
I	7,200	7.59
J	7,300	3.38
K	12,700	2.32
L	14,500	2.32

*Calculated by the technique outlined by Vacquier et al. (1951).

north side of the high-gradient band along Heyl's (1972) 38th parallel lineament, most of the prominent positive total magnetic intensity anomalies analyzed are related to large structural trends. One such trend is evidenced by the north-south arrangement of anomalies E, F, and G, together with lateral anomalies D and H (pl. 1). This predominantly north-south trend merges rather smoothly on the south with the series of positive anomalies on the north side of the high-gradient band along the 38th parallel lineament. The north-south positive anomaly trend nearly parallels the Du Quoin Monocline to the east. Correlation of these anomalies with the Du Quoin Monocline can be made only in the broadest sense. The Du Quoin Monocline represents a zone of weakness, where intrusive activity might have taken place. On the other hand, it may well be that the area west of the Du Quoin Monocline and north of the 38th parallel has been subjected to more intrusive activity than has the Fairfield Basin to the east of the monocline.

The positive anomaly labeled K, centered in Tps. 11 and 12 S., Rs. 3 and 4 W., Union County (pl. 1) is undoubtedly related to the Ste. Genevieve Fault Zone in Illinois. The magnetic high, which is located on the upthrown side of the fault, is totally enclosed by the southward-curving fault zone. The method of Vacquier et al. (1951) applied to this anomaly provided a depth of 13,300 feet (12,700 feet below mean sea level) to the top of the anomaly-producing mass and a corresponding susceptibility contrast of 2.32×10^{-3} cgs units. Although these calculations do show that the anomaly is due, at least in part, to a lateral susceptibility contrast such as that produced by a basic body at depth, part of this anomaly may be the result of a smaller lateral susceptibility contrast at the granite-sediment contact. There is evidence of nearly 2,000 feet of structural relief in the sedimentary rocks associated with this fault zone, and some of this relief undoubtedly is prevalent on the basement surface. More information concerning this zone is afforded by gravity data covering this area. A Bouguer gravity anomaly profile with orientation perpendicular to the observed strike of the fault zone and perpendicular to the steepest gravity gradients has been constructed (fig. 9).

The theoretical formula derived by Nettleton (1940) for the gravity anomaly produced by a fault was used with the following parameters: thickness of the anomalous slab - 2,000 feet; depth to the top of the anomalous slab below mean sea level (obtained from magnetic data) - 12,700 feet. From these data the density contrast was calculated to be 0.30 gm/cm^3, which is about the contrast one might expect at a granitic-basic contact.

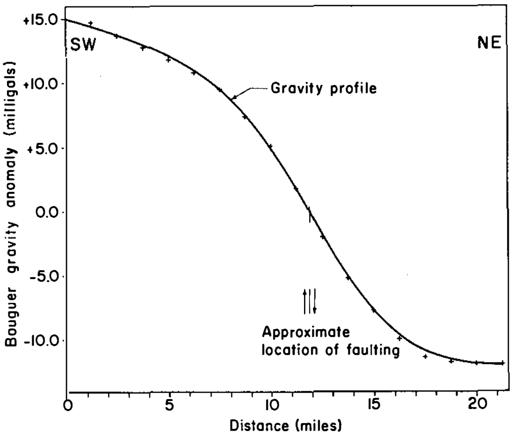


Fig. 9 - Bouguer gravity anomaly profile perpendicular to the strike of the Ste. Genevieve Fault Zone in T. 11 S., R. 2 W., Union County, Illinois.

The other closed magnetic high south of the high-gradient band, the anomaly labeled L (pl. 1), is not readily correlated with any one known geologic structure. There are numerous known folds and faults in this area. The method of Vacquier et al. (1951) provides a depth to the top of the anomalous body of 14,900 feet (14,500 feet below mean sea level) and a corresponding susceptibility contrast of 2.32×10^{-3} cgs units.

Here again, the anomalous mass appears to consist of iron-rich (basic) material. The significant fact here is that the top of this anomalous mass is farther from the earth's surface, as well as being farther below the basement surface, than the other prominent anomalies to the north. Schafersman (1973), using gravity data collected by the Illinois State Geological Survey, assumed the anomalous mass to be a right circular cylinder whose base is located at the base of the crust. Her calculations provided a cylinder having a radius of 6.2 km whose top was at a depth of 8 km below mean sea level and whose density contrast was 0.35 gm/cm^3. We made calculations with these same data, also assuming a right cylindrical anomalous mass, but with a square cross section and its base at the Conrad Discontinuity. These calculations provided a body 9 km on a side whose top was 8 km below mean sea level and whose density contrast was 0.40 gm/cm^3.

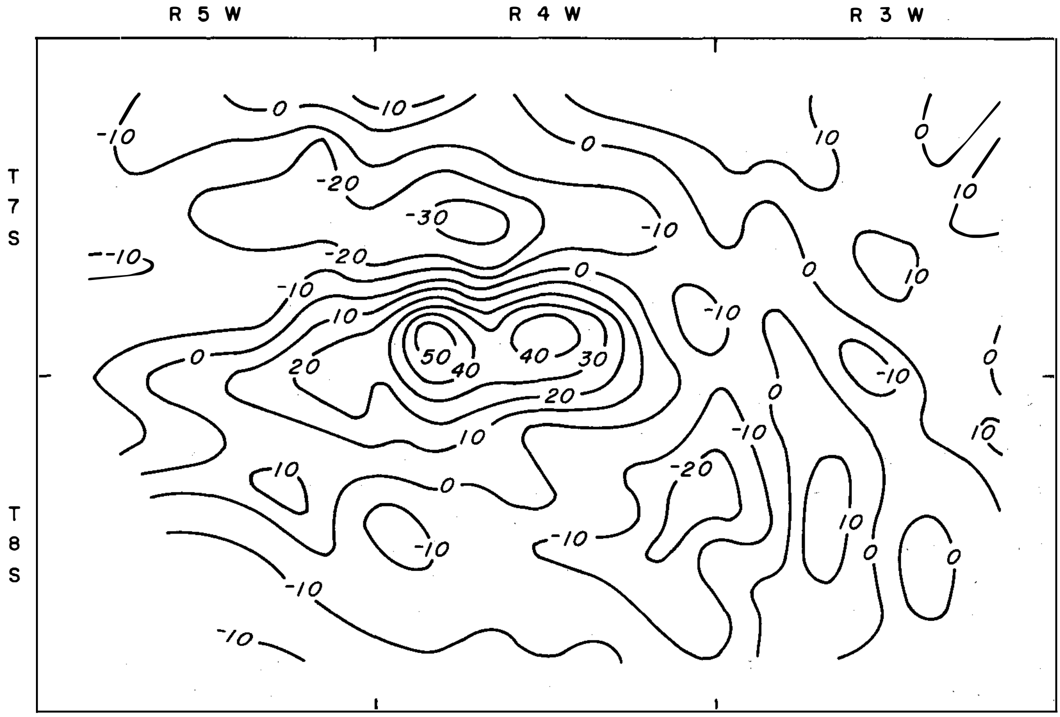
The disparity between the depths to the top of the anomalous mass calculated from magnetic data and gravity data is probably due to the fact that the actual shape of the anomalous mass is significantly different from that of a right cylinder with a flat top. In reality, the anomalous mass, which one might imagine to be a stock or a batholith, probably is tapered rather than cylindrical and probably is not flat at the top.

On the residual total magnetic intensity map it is difficult to visually separate anomalies that are due to topographic relief on the basement surface from anomalies that are due to lithologic changes within the basement rocks. Thus far, only the latter type anomalies have been discussed.

In order to show that anomalies due only to topographic relief on the basement surface do exist, the anomaly centered in T. 7 S., R. 4 W., Jackson County, was examined (pl. 1). This anomaly appears as a nose superimposed on the high-gradient band associated with Heyl's 38th parallel lineament. The location of this anomaly is coincident with the Ava-Campbell Hill Anticline.

The first step in the analysis of this anomaly involved removal of the regional trend from the residual total magnetic intensity field to produce a secondary residual anomaly (fig. 10). Next, a Vacquier model applied to this residual anomaly provided a depth to the top of the anomaly-causing mass of 8,250 feet (7,700 feet below mean sea level). This is the approximate depth of the crystalline basement surface in this area. Further analysis indicates that the lateral susceptibility contrast producing this anomaly is 3.41×10^{-4} cgs units. This value is of the same order of magnitude as the susceptibility values for the granite and rhyolite samples obtained from boreholes in and around the study area. Therefore, it is reasonably safe to infer that the observed anomaly is due to topographic relief on the basement surface.

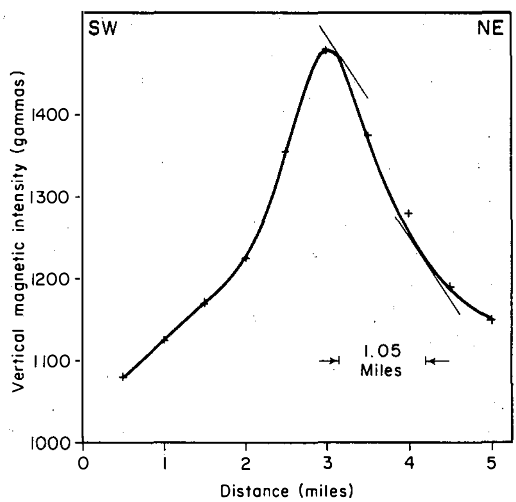
Another example of a magnetic anomaly related to topographic relief on the basement surface is an anomaly shown by Chang (1958) and Segar (1965) in T. 4 S., R. 10 W., Monroe County, which is south of, but collinear with, the Waterloo and Dupo Anticlines (fig. 5). In this area Chang (1958) and Segar (1965) have collected ground vertical magnetic intensity data that show an elongate anomaly with steep lateral gradients here. The steep lateral gradients, together with the limited areal extent of this anomaly, are indicative of a rather shallow source. A ground vertical magnetic intensity profile has been constructed perpendicular to the long axis of this anomaly, the greatest value occurring in T. 4 S., R. 10 W., Monroe County (fig. 11). Peters's half-slope method (1949) for determining the depth to the top of the source of this anomaly yielded a depth of approximately 3,500 feet. The deep borehole in Sec. 35, T. 1 S., R. 10 W., Monroe County, located near the top of the Waterloo Anticline, encountered red granite at a depth



Contour interval = 10 gammas

Fig. 10 - Secondary total magnetic intensity residual map of the Ava-Campbell Hill anomaly.

of 2,759 feet. A corresponding anomaly is not apparent on the residual total magnetic intensity map (pl. 1). One reason for this discrepancy may be that the flight lines of the aeromagnetic survey were north-south and therefore closely aligned with the long axis of such an anomaly. Another, more compelling reason may be that at 3,000 feet above mean sea level such an anomaly measurable at the surface would be too diminished to be discernible.



Depth to top of anomalous body = 3,463 ft (based on Peters's half-slope method)

Fig. 11 - Vertical magnetic intensity profile perpendicular to long axis of anomaly in T. 4 S., R. 10 W., Monroe County, Illinois. (Data from ground vertical magnetic intensity survey by Chang, 1958.)

DISCUSSION

The aeromagnetic survey of southwestern Illinois has shown that there is considerable lithologic variation within the igneous rocks of the earth's crust above the Curie Point Geotherm in this area. This variation was suspected from previous studies of potential fields in southern Illinois (Patenaude, 1964; McGinnis and Bradbury, 1964; Segar, 1965; and Schafersman, 1973). Bouguer gravity anomaly maps of Illinois (McGinnis et al., 1976) and Kentucky (Watkins, 1963) show that southern Illinois and western Kentucky in and around the northern end of the Mississippi Embayment possess a regionally denser crust than those areas away from the Embayment. Since there is tangible evidence of basic intrusions both east and west of the study area, it is reasonable to assume that basic intrusions are the cause of some large positive magnetic anomalies observed in the study area. Theoretical analyses of some of the more prominent total magnetic anomalies have yielded depths and magnetic susceptibility contrasts that support this interpretation. While there is no evidence that basic intrusions penetrate the sediments anywhere in the study area, the possibility that they do has not been negated by this survey. The fact that this survey was flown at 3,000 feet above mean sea level might prevent small anomalies due to localized shallow intrusions from being discerned. Perhaps the prominent positive total magnetic intensity anomalies observed are related to anomalous masses best described as parent bodies. None of these so-called parent bodies has been determined to penetrate above the basement surface, although they appear to be close to the basement surface in the northern part of the study area. These findings, together with the fact that the basement surface at its shallowest point in the study area is of the order of 3,000 feet deep, tend to rule out any economically feasible pursuit of iron ore here at the present time.

The high magnetic gradient band that traverses the study area in an approximately east-west direction through Randolph, Jackson, and Williamson Counties (pl. 1) actually persists across the entire breadth of southern Illinois through Hardin County. In the study area, this anomalous band is correlative with the Cottage Grove Fault System, but on a more regional scale it correlates with the 38th parallel lineament of Heyl (1972). While the Cottage Grove Fault System does not possess displacements in the sedimentary rocks as large as some of the other components of the 38th parallel lineament, there is no diminution of the anomalous high-gradient band where it follows the Cottage Grove Fault System. Theoretical calculations indicate that this high-gradient band has as its source an abrupt lateral change in lithology in the igneous rocks of the upper crust, the more iron-rich rocks being to the north. Quite conspicuously, along the north side of this anomalous band, there are sizable closed total magnetic intensity highs that have been interpreted as caused by dikelike basic intrusive bodies.

It is well known that intrusive activity has taken place along Heyl's 38th parallel lineament at different times throughout geologic history.

In the St. Francois Mountains of southeastern Missouri, there are mafic intrusions of Precambrian age. Some of these intrusions have been encountered in areas where the basement rocks crop out, and some have been found by drilling through the relatively thin sedimentary cover in the area around the basement outcrops. There is little doubt that in some cases the areal extent of the mafic rocks at the basement surface here has been enlarged by erosion of the basement surface subsequent to emplacement of the intrusions. Some intrusions have been truncated and others merely exposed by erosional processes.

The acidic basement rocks of the St. Francois Mountain area and of that part of the study area where wells have penetrated and sampled basement (the northern part of the study area) are similar to each other in age and lithology. No such comparison can be made between the basic rocks of the basement in these two areas simply because no Precambrian basic rocks have been encountered in the study area. However, it does seem reasonable to assume that Precambrian basic intrusives similar to those in the St. Francois Mountains do exist in the study area and that these intrusives are capable of producing sizable anomalies such as those observed.

The Ozark Dome, a positive feature in Precambrian time, has been subjected to periods of uplift from early Paleozoic time. (Recent seismic activity in this area suggests that deep-seated movement is still taking place.) Structural features such as the Ste. Genevieve Fault Zone are the results of some of these uplifts. Basic intrusions along the Ste. Genevieve Fault Zone at Avon, Missouri, have been dated as Early and Middle Devonian. This time corresponds to a period of considerable movement along this structure. The residual total magnetic intensity map (pl. 1) shows a positive anomaly associated with the upthrown side of the Ste. Genevieve Fault Zone in Union County, Illinois. Theoretical analyses of this anomaly indicate that basic intrusions may be associated with the faulting here.

Throughout the study area and the remainder of southern Illinois, there are a number of zones of weakness along which there has been considerable movement since the Precambrian. It is possible that these zones of weakness extend deep into the crust and served as access channels into which basic intrusives have entered from time to time. Some of the basic intrusives in and around the study area (postulated and/or real) are thought to have been emplaced at the close of the Paleozoic, perhaps contemporaneously with the Appalachian Revolution, and some others possibly as late as Cretaceous time in association with crustal downwarping in the Mississippi Embayment.

Besides the magnetic anomalies related to lithologic variation within the igneous rocks of the earth's crust above the Curie Point Geotherm in the study area, there are also relatively small magnetic anomalies caused by relief on the basement surface. These latter anomalies are often obscured by superposition of the former anomalies. It has been demonstrated, in the case of the Ava-Campbell Hill Anticline, that a positive total magnetic intensity anomaly due to relief on the basement surface is related to an upwarping of overlying sedimentary rocks. Although delineation and interpretation of these anomalies caused by basement relief require a rather high degree of scrutiny, there is little doubt that magnetic methods are far superior to gravity methods for this purpose in the study area (and in all of Illinois). The lateral magnetic susceptibility contrast at this interface provides a much clearer geophysical signature than the corresponding lateral density contrast.

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